

# Mapping Pollutant Concentration Using R Shiny Web Framework Visualization in Manado City

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## Abstract

<b>Keywords:</b> Mapping; Pollutant; R Shiny; Geographic Information System; Manado City	Air quality monitoring in Manado City presents significant challenges in data interpretation, as conventional static tabular presentation limits effective understanding by non-technical users. This study collected primary data from 312 field measurement points across Manado City, then developed a web-based visualization application using the R Shiny framework, integrating Geographically Weighted Regression (GWR) analysis and Air Pollution Standard Index (ISPU) calculations to present air quality data interactively. The system was developed following a modified Waterfall methodology and implemented using the R programming language with supporting packages including shiny, leaflet, shinydashboard, and sf. The key contribution of this research lies in the integration of GIS-based spatial analysis with an interactive web dashboard to democratize environmental data access for non-technical users. Black Box Testing confirmed that all functional requirements were met. The implementation results demonstrate that the application successfully delivers responsive interactive visualizations including a thematic pollutant distribution map, variable control panels, and a searchable database, assisting users in understanding air quality conditions through an informative and user-friendly web interface.
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## 1. INTRODUCTION

The rapid growth of urbanization and the intensity of transportation activities in Manado City have had a significant impact on increasing the risk of air pollution [1]. Air quality monitoring data, which includes crucial parameters such as Particulate Matter (PM<sub>2.5</sub> and PM<sub>10</sub>) and Carbon Monoxide (CO), is a vital information asset for the government and the public to mitigate environmental health impacts [2],[3]. However, the availability of the from field measurements alone is not sufficient to provide meaningful insights.

The fundamental challenge faced today is not the lack of data, but rather the phenomenon of information overload, where the challenge lies in how the data is managed, processed, and presented so that it is easily understood by non-technical users in order to support targeted decision making [4]. Until now, air quality data reporting mechanisms have often been presented in static tabular formats or rigid conventional report documents [4]. This presentation method has significant limitations in terms of interactivity and information accessibility, which often causes excessive cognitive load for users. The public and the general community often find it difficult to identify spatial distribution patterns, filter data based on specific regions, or quickly understand pollution fluctuation trends. These limitations hinder the process of data interpretation, which should be intuitive.

From an Information Technology perspective, the gap between the complexity of environmental statistical data and end-user understanding is a classic problem in the domain of Data Visualization and Human-Computer Interaction, which requires a transformation from static data presentation to dynamic visualization that can improve information absorption [5]. Previous studies have investigated air quality mapping and web-based environmental dashboards. Pontoh et al. [9] developed air quality mapping in



Bandung City, while Farhan et al. [6] demonstrated the use of R Shiny for forest fire monitoring in West Kalimantan. However, none of these studies have explicitly addressed the integration of GWR-based spatial analysis with an interactive, non-technical user-oriented web interface for urban air pollution mapping. This study addresses this gap by developing a WebGIS dashboard that combines GIS-based spatial analysis with a fully interactive R Shiny application designed specifically for public accessibility.

The R Shiny Web Framework is a highly relevant and powerful technological solution for this need [6]. Unlike conventional web development, which often separates the processes of data analysis and interface development, R Shiny enables seamless integration between the statistical computing power of the R language and modern web interfaces (HTML, CSS, and JavaScript) without requiring complex front-end coding [7]. This capability enables the development of a Geographic Information System (WebGIS) dashboard that not only displays location maps, but also includes complex data analysis logic, allowing users to interact directly with the data model presented [8]. The use of R Shiny in mapping pollutants in Manado City is a strategic step in the context of developing an environment-based Decision Support System [9][10]. With web-based visualization, information about pollution hotspots can be democratized, meaning it can be accessed widely (ubiquitous access), transparently, and based on actual data (evidence-based) by anyone. [11].

Therefore, this study focuses on designing a visualization of pollutant levels using the R Shiny Web Framework. This study is very important to prove how information technology can play an active role in improving the community's environmental data literacy and supporting the Smart City initiative, particularly in the Smart Environment pillar in Manado City, through the provision of an effective, efficient, and interactive information platform.

## 2. RESEARCH METHOD

### 1. Research Method

The research stages are arranged systematically, starting from problem identification to system testing, as illustrated in Figure 1. This approach was chosen to ensure that each development phase, from environmental data analysis to interface visualization, is well documented and runs linearly.

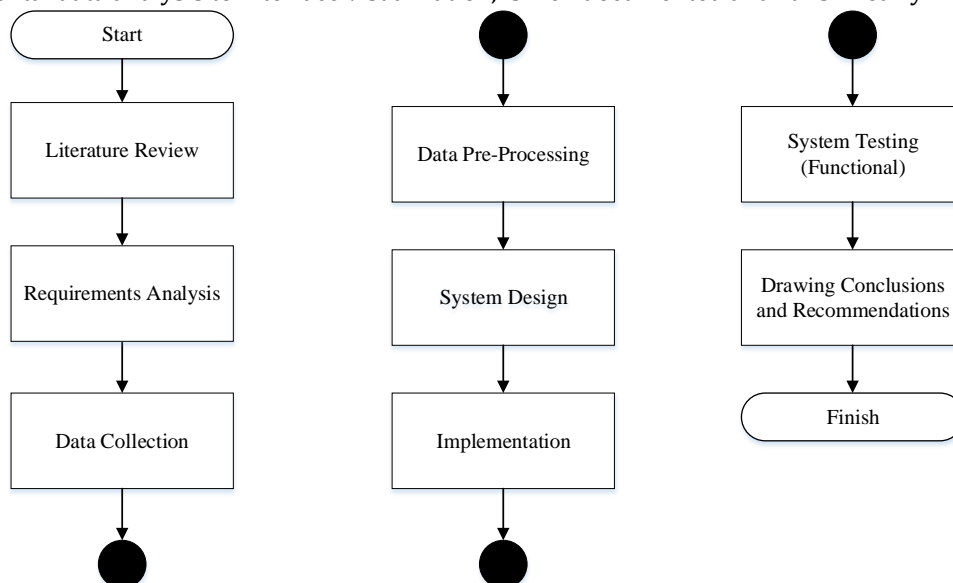


Figure 1. Research Methodology Flow

#### a. Literature Study

The initial stage focused on gathering theoretical references on R Shiny Web Framework technology, digital mapping libraries (Leaflet.js), and air quality standards applicable in Indonesia. This study aims to understand the technical capabilities of the R programming language in handling interactive spatial data visualization.

#### b. Requirements Analysis

At this stage, the functional requirements of the system are identified. The target users of the system are the general public and the city government, so the main requirements defined include:

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- A. Easy access without logging in.
- B. Ability to display responsive interactive maps.
- C. Data filtering feature based on pollutant parameters (PM2.5, PM10, and CO).
- D. Availability of detailed information through click interaction (popup).

*c. Data Collection*

The data used in developing this system is primary data from air quality measurements in Manado City in December 2025. Measurements were carried out using a portable air quality detector at 312 observation points distributed across all sub-districts in Manado City, ensuring spatial representativeness across urban, sub-urban, and peri-urban areas. Data attributes recorded at each point include geographic coordinates (latitude/longitude), pollutant concentration values (PM2.5, PM10, CO), and supporting environmental metadata.

*d. Data Pre-processing*

Given that this study focuses on WebGIS development, the air pollution analysis stage serves as a data preparation process (backend processing). Raw measurement data is not visualized directly [12], but is first processed using the Geographically Weighted Regression (GWR) statistical algorithm and Air Pollutant Standard Index (ISPU) calculations [13], [14].

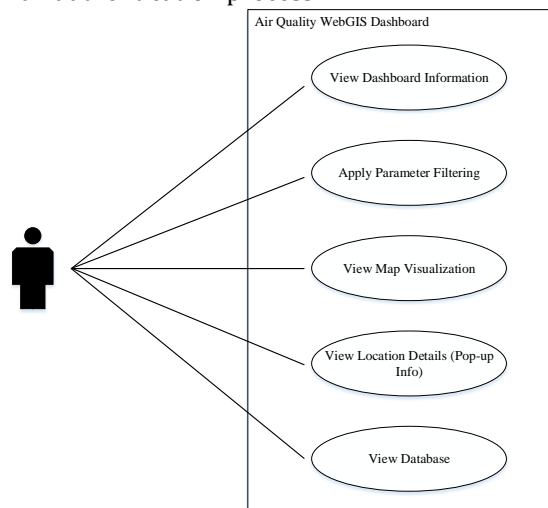
- A. Data Transformation: Concentration values are converted into index values (ISPU) and regression coefficient values.
- B. Data Format: The results of the statistical analysis are then exported into a structured spatial data format (Spatial Dataframe) or Shapefile, so that they can be read quickly by the R Shiny engine without burdening server performance when the application is running.

*e. System Design*

The design phase aims to translate user requirements into technical specifications. The design is carried out using Unified Modeling Language (UML) modeling, which consists of Use Case Diagrams and Activity Diagrams to describe system behavior.

**A. Use Case Diagram**

Use Case Diagrams are designed to map interactions between users and the features available in WebGIS. In this system, there is one main actor, namely Public Users, who have full access rights to information without having to go through an authentication process.



**Figure 2.** Use Case Diagram

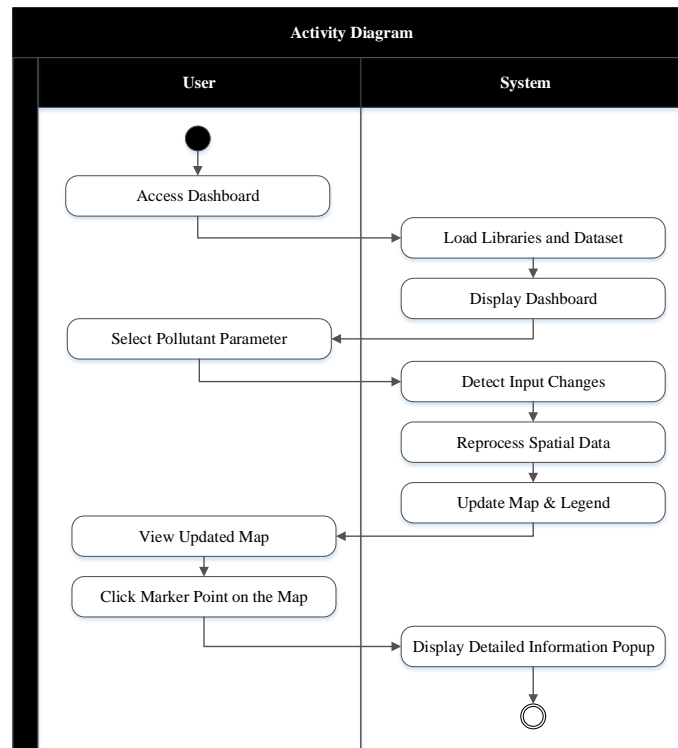
Based on the design, there are five main functionalities that users can perform:

- Users can open the home page that displays statistical summaries (Average ISPU, Maximum Value, and Model Accuracy).
- Users have control to select the variables they want to display on the map.

- Users can perform spatial navigation such as zooming in, zooming out, and shifting the map to specific areas in Manado City.
- When users click on a marker or point on the map, the system must display an information window (popup) containing details of the sub-district name and specific air quality figures.
- Users can switch to the table page to view data in rows and columns and perform text searches.

**B. Activity Diagram**

Activity Diagram depicts the procedural workflow of the system, starting from when the user opens the application until the information is displayed. This flow explains the reactivity logic that is the advantage of R Shiny.



**Figure 3.** Activity Diagram

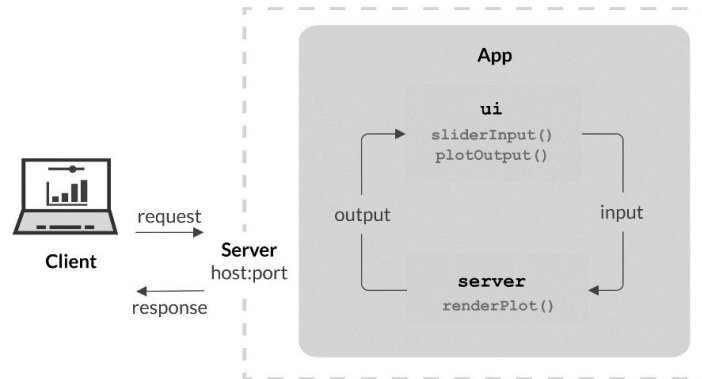
The system activity flow is described as follows:

- When users access the application URL, the R Shiny server will load the necessary packages (shiny, leaflet, dplyr) and read the spatial dataset into memory.
- The system displays a user interface (UI) in the form of a basemap of Manado City along with a sidebar control panel.
- Users interact by selecting one of the parameters in the dropdown menu.
- The server detects these input changes and automatically refilter the data (data subsetting) according to the selected parameters.
- The system updates the color layers on the map according to the new data without reloading the entire web page. The map legend also automatically adjusts to the new data value range.

*f. Implementation*

Implementation was carried out using the R programming language in the RStudio integrated development environment. R Shiny was selected as the core framework because it enables seamless integration between R's statistical computing capabilities and modern web interfaces (HTML, CSS, and JavaScript) without requiring complex front-end coding [7]. Architecturally, R Shiny separates visual design from data processing logic through two fundamental components the User Interface (UI) and the Server where the UI defines what users see on the client side while the Server handles statistical computations in the background [15]. This reactive architecture allows the system to update map displays and filter data in real-time without reloading the entire page, which is critical for an interactive spatial application.

Supporting packages used in implementation include leaflet for interactive mapping, shinydashboard for the dashboard layout, sf for spatial data handling, dplyr for data manipulation, and spgwr for Geographically Weighted Regression processing.



**Figure 4.** R shiny Application Structure

*g. Testing*

Testing was conducted using the Black Box Testing method. The focus of testing was to validate the functionality of features that had been built during the design stage, such as ensuring that the filter button worked, that maps appeared with the correct coordinates, and that the system ran responsively.

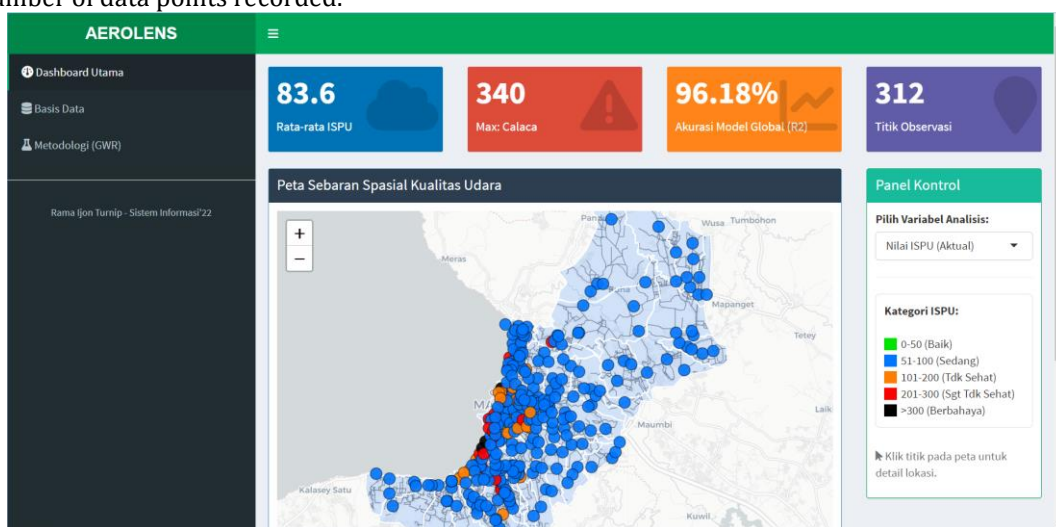
**3. RESULTS AND DISCUSSION**

*1. Implementation of Web-Based Geographic Information System*

To facilitate public access to air quality information and spatial analysis results, this study developed a web-based Geographic Information System. The system was built using the R Shiny framework, utilizing the leaflet library for interactive map visualization and shinydashboard for the user interface. This implementation integrates field measurement data and data processing results into a single integrated dashboard.

*2. Main Dashboard Interface*

The system's main page displays a monitoring dashboard that provides statistical summaries and a map of observation points. At the top (Info Boxes), key information is displayed in the form of data results and the number of data points recorded.



**Figure 5.** Main Display of the Air Quality Web Dashboard

In the image, the basemap is supplemented with administrative boundary layers (Loc.shp) and road networks (Jalanmdc.shp) to provide clearer spatial context.

a. Sidebar Panel (Navigation)

Located on the left side of the screen, this panel functions as the main menu that contains page navigation, such as Main Dashboard, Distribution Map, Database, and About the Application. This design makes it easy for users to quickly move between modules.

b. Interactive Control Panel (Input Widget)

On the map page, there is a control panel on the right side that allows users to customize the data display, such as a dropdown menu to select pollutant parameters (ISPU, CO, PM10, or PM2.5) and checkboxes to filter points based on health categories.

c. Interactive Map (Leaflet Map)

This is the main visual component that displays the distribution of observation points on a basemap of Manado City. The map is equipped with Zoom & Pan features, as well as dynamic markers according to the ISPU category level.

d. Information Window (Popup)

This feature activates when the user clicks on one of the marker points. The system will display a popup window showing detailed location information, including: Village Name, Point Code, Pollutant Concentration Value, and actual ISPU Value.

3. Spatial Distribution Visualization of Actual ISPU

The main feature of this system is mapping the actual air quality conditions based on the Air Pollution Standard Index (ISPU). The system uses a dynamic color scheme in accordance with KLHK standards: Green (Good), Blue (Moderate), Yellow (Unhealthy), Red (Very Unhealthy), and Black (Hazardous).

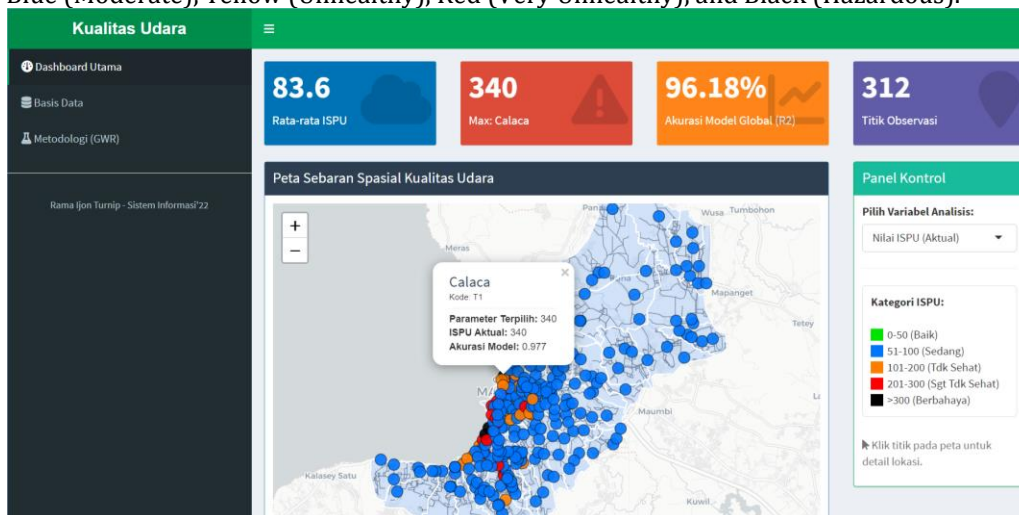


Figure 6. ISPU Distribution Visualization

On this display, users can interact by clicking on each point (marker) and the system will bring up an information window (popup).

4. Variable Control Panel

In addition to the map feature, the system provides access to tabular data through the "Database" menu. This page contains all research data, ranging from coordinates and pollutant concentration values to calculation results.

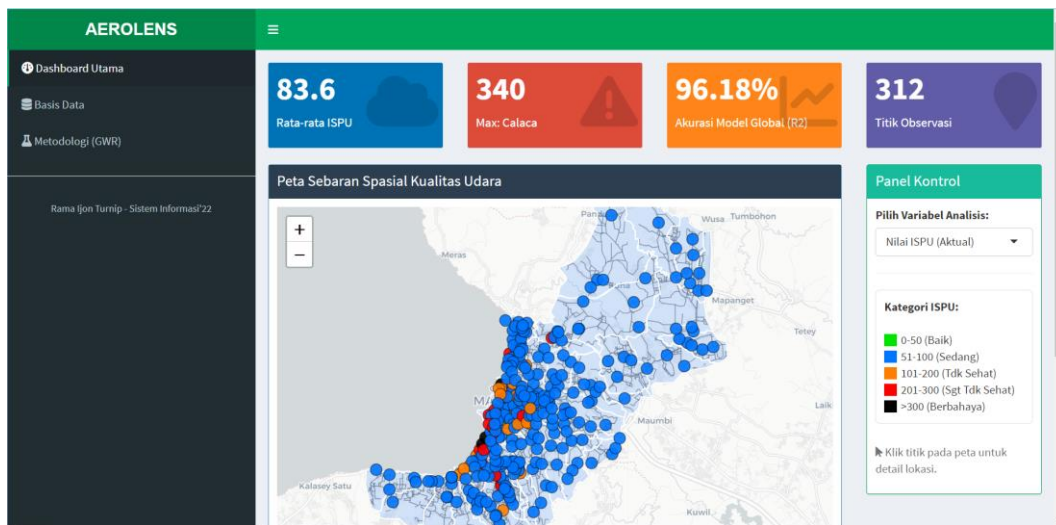


Figure 7. Variable Selection Control Panel

### 5. Database

In addition to the map feature, the system provides access to tabular data through the “Database” menu. This page contains all research data, ranging from coordinates and pollutant concentration values to calculation results.

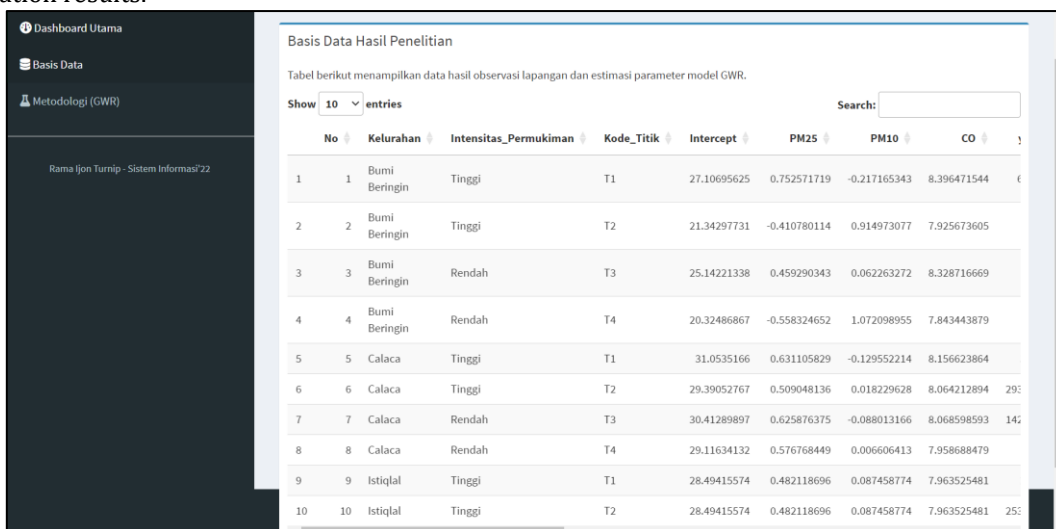


Figure 8. Display of the Observation Results Database Page

### 6. Testing

Functionality evaluation of the system was conducted using the Black Box Testing approach, which included verification of the interface, data processing logic, and map interactivity. The test results showed that all system components performed according to design specifications (Valid). Specifically, the dashboard interface was able to display statistical data aggregation. The core feature of WebGIS, namely mapping visualization, proved to be responsive in handling parameter changes; the system automatically adjusted color symbology and legends when users switched between coefficient value displays. In addition, validation of supporting features such as data searches (search queries) in database tables and pop-up interactions for information per sub-district showed that the system was able to present data details accurately without technical obstacles.

## 7. Discussion

The implementation of R Shiny in this study successfully transformed tabular air quality data into interactive and easy-to-understand geospatial information. Unlike conventional static data presentation, this web-based visualization allows users to explore pollution distribution patterns dynamically.

### a. Effectiveness of Zoning Mapping

Through interactive mapping features, the system is able to clearly visualize the results of spatial analysis. The use of a color gradient scheme on the map has proven effective in distinguishing air quality zoning. Areas with high pollutant concentrations, such as in the city center (Kelurahan Calaca), are automatically mapped with red markers (Unhealthy/Hazardous Category). Conversely, suburban areas with high vegetation are visualized in green or blue. This makes it easier for stakeholders to instantly identify pollution hotspots without having to analyze raw numbers.

### b. Spatial Data Interactivity

The main advantage of this system lies in its ability to filter data in real-time. Based on test results, users can change the display variable from CO to PM10 parameters in seconds. This feature provides in-depth insight that the distribution pattern of gaseous pollutants (CO) tends to follow primary arterial routes due to motor vehicles, while particulate dust has a more random distribution pattern.

### c. Public Information Accessibility

The integration of Leaflet in the R Shiny framework makes this map very lightweight and responsive when accessed via a web browser. Information about "Spatial Analysis," which was previously complex and only understood by statisticians, can now be presented in the form of simple information pop-ups. The public can find out the air quality level at their specific location with just one click, making this application an effective medium for environmental education.

## 4. CONCLUSION

This study successfully developed and implemented an R Shiny-based web application as an interactive visualization medium for air quality data in Manado City, accessible via any standard web browser without authentication. Based on 312 observation points processed through GWR spatial analysis and ISPU calculations, the application achieved 100% functional validity across eight Black Box test cases. The system demonstrated that the R Shiny framework effectively bridges the gap between complex spatial statistical outputs and non-technical end-users through interactive dashboards, thematic pollutant distribution maps, real-time variable control panels, and a searchable database. Areas of highest pollutant concentration were identified in central urban sub-districts, while suburban areas showed considerably lower ISPU values, a finding consistent with GWR derived spatial heterogeneity patterns. Overall, this research confirms that web based development using R Shiny is an effective approach for building environmental data visualization systems, with opportunities for future development in continuous real-time data integration, system performance optimization, and expanded pollutant parameter coverage.

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